

ELECTROMAGNETIC STUDY OF ARCTIC SEA ICE

Robert G. Onstott

Earth Sciences Group, Environmental Institute of Michigan, International

P.O. Box 134008, Ann Arbor, Michigan 48113-4008

phone: (313) 994-1200 ext 2544, fax: (313) 994-5824, e-mail: onstott@erim-int.com

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LONG TERM GOAL

My long term goal is to advance the understanding of the electromagnetic behavior of sea ice and snow. The ultimate goal is to improve the retrieval of geophysical and internal properties of sea ice using remote sensors. Geophysical information of particular interest includes: ice form, ice thickness, snow thickness, state-of-melt, and state-of-freeze up.

SCIENTIFIC OBJECTIVES

The objectives of this project are to:

- Investigate the relationships between the physical (temperature, salinity, crystal structure, inclusions) and electromagnetic (microwave) properties of natural sea ice; and
- Measure the microwave scattering behavior of a media which is highly complex, both monostatically and bistatically, over a diverse range of micro- and millimeter-wave frequencies.

APPROACH

A series of comprehensive laboratory and field experiments, which focused on study cases that supported the development of forward and inverse models, were conceived and conducted during the period from 1993 through 1995. Four investigations were conducted at the U.S. Army Cold Regions and Research Engineering Laboratory. Two field investigations were conducted near Barrow, Alaska and Resolute Bay, Northwest Territories, Canada. Our contribution to the ARI-EM multidisciplinary program was to measure the active microwave properties of sea ice and snow, and formation conditions at various ice study sites (Barber et al, Grenfell et al., Onstott et al., and Perovich et al., submitted), as well as to characterize certain aspects of the sea ice scene (e.g., dielectric constant based on nadir reflectivity, surface roughness statistics, and general scene character).

In addition, special projects were conducted in collaboration with C. Roesler (UConn) to study sites that revealed high concentrations of entrapped material, and F. Tanis (ERIM) to study the interrelationship between optical transmission and scattering, and microwave reflectivity and backscatter during the transformation of sea water to young ice.

Microwave behavior was measured *in situ* using an instrumentation radar which operated both monostatically (0.5 to 95 GHz, Quad-Pol, 0°-60° incidence angle) and bistatically (0.5 to 12 GHz, HH-Pol, 20°-45° incidence angle). Backscatter intensity as a function of position from the radar was recorded and allows comparison with the physical property profile information. Operating the radar at the zenith angle allowed the bulk reflectivity from the composite of snow, ice, and ocean to be measured at selected frequencies.

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WORK COMPLETED

Data analyses and model building efforts have been completed. Final drafts of the remaining papers from this program are being circulated to co-authors.

RESULTS

The backscatter time history of the evolution of open water into young ice (see Fig. 1), grown under quiescent conditions, has been made and compared to the passive microwave response (Grenfell et al., submitted). A prominent reflectivity feature is the decrease in the effective permittivity of the ice/water system. In addition, the backscatter starts at very low levels and then generally increases as the ice thickens to 5 cm during its first 30 hours of growth. Very weak backscatter is associated with the initiation of the new ice layer.

A backscatter response was also obtained for ice growth under wave conditions (see Fig. 2). Comparison of the pancake ice shows a microwave behavior quite different from that of ice grown under quiescent conditions. Waves cause frazil and pancake ice to form. Discussions of the electromagnetic and physical properties of frazil and pancake ice have also been made (Onstott et al., submitted). The time evolution behavior is found to be different at each of the three frequencies shown. A uniqueness in the frequency and time response behavior strongly suggests that a remote sensing system, which is diverse in frequency or wavelength, will yield more information regarding the state of ice properties than a single parameter system. Changes in behavior "modes" are associated with the discrete events, which include the initiation of the formation of slush and the initiation of pan formation. The ability to discriminate between the various ice forms and formation conditions is important to the monitoring of features such as polynyas and the marginal ice zones, which are regions where new ice is produced. The ability to estimate flux of brine to the upper ocean also improves with the ability to discriminate among these various ice forms.

The results of a spring field study show a strong relationship between the microwave response of snow drifts and shallows on level first year ice. In Fig. 3a, a 2-D snow depth profile is shown for a 100 m square area. In Fig. 3b an aircraft SAR image with 6 m ground resolution shows a mottled intensity pattern. Fig. 3c is an image based on data acquired by a surface-based scatterometer with 1 m resolution. It is found that during the later part of spring, the snow at the snow-ice interface is in the form of a hoar layer whose crystals are enlarged. In snow shallows, the presence of enlarged hoar layer crystals provides a backscatter intensity enhancement of 1-3 dB. This causes a mottled look to the spatial pattern of the SAR image. This intensity modulation is driven by snow shallow and drift spatial statistics as well as snow thickness.

Onstott has proposed that the use of effective reflectivity and dielectric constant is more robust in describing the microwave backscatter for a floating ice sheet less than a wavelength in thickness. This was confirmed in modeling by using a dense medium scattering model based on the standard radiative transfer formulation with a scattering phase function for groups of scatterers, and surface scattering due to air-ice and ice-water boundaries accounted for by the integral equation surface scattering model. Results indicate that for thin ice the contribution of water under the ice sheet in the form of producing an effective impedance at the air-ice interface is a dominating factor. Reflectivity measurements confirm this result. In addition, the

ice volume contribution is 1-3 orders of magnitude lower for ice thicknesses of 0-7 cm (Fung and Onstott, 1996).

IMPACT/APPLICATION

This project is focused on the documentation of the active microwave properties of sea ice. An improved understanding of the relationship between the physical properties of sea ice and its electromagnetic response will allow for the improvement in the development of forward and inverse scattering models, and in the ability to retrieve sea ice property information from satellite-based remote sensors.

TRANSITIONS

None.

RELATED PROJECTS

An integrated electromagnetic-thermodynamic model to predict ice growth rates, thickness, and EM signatures, and the empirically derived association of SAR signature, ice form, and thickness are being used to support an international sediment drilling program which is working on landfast sea ice off of the coast of Cape Roberts, Antarctica (funded by NSF).

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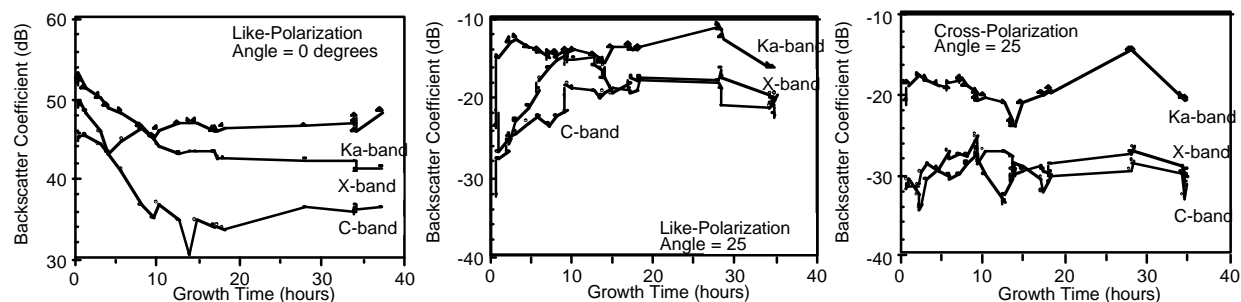


Figure 1. Observations of radar backscatter coefficients of the transition from open water to young sea ice when conditions are calm for C-, X-, and Ka-band frequencies, vertical and 25° angles of incidence, and like- and cross-polarizations.

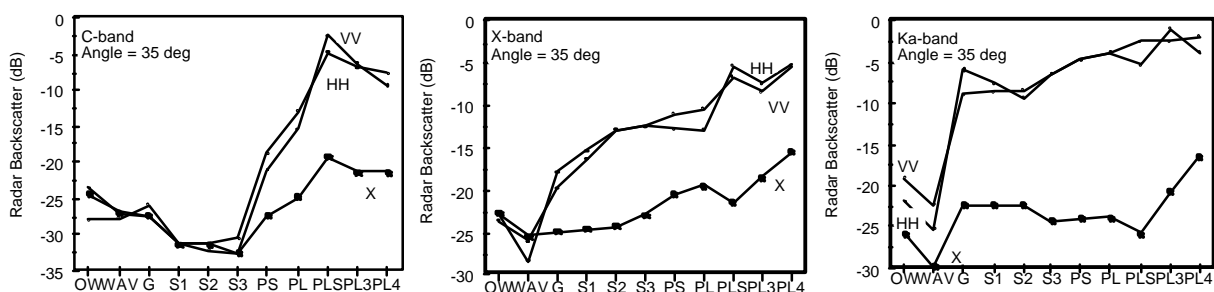


Figure 2. Observations of the microwave response of sea ice growth when waves are present include open water (OW), water with wave action (WAV), grease ice (G), slush ice (S), and pans of ice (P). Large pans are indicated with L, and the freezing of a pan surface with S. Numbers indicate an additional time increment in the decimal day of 0.05-0.1 days.

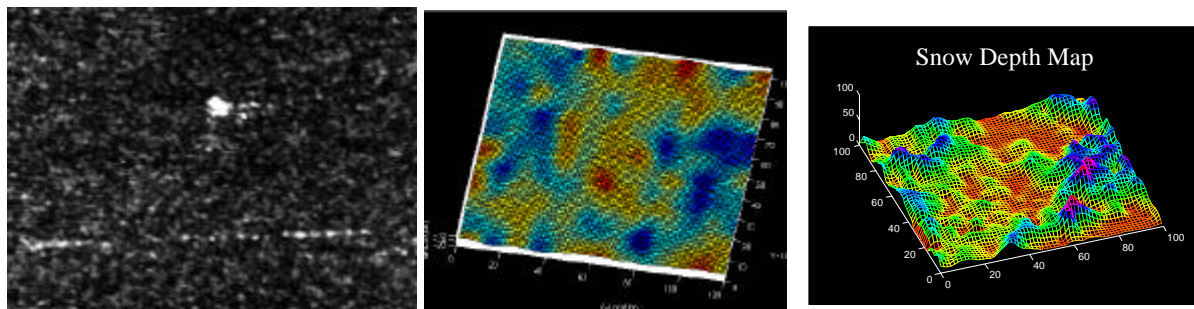


Figure 3. In the first frame, a snow depth profile is shown for a 100 m square area. Snow depths range from 5-120 cm. In the second frame, a SAR image with 6 m ground resolution which includes the study area is shown. The bright cluster near the image center is the site tent facility. The mottled look of the terrain is due to a backscatter enhancement in regions of thin snow cover which also have a well-developed hoar layer at the snow-ice interface. In the third frame a 100 m square image produced by a surface-based scatterometer with 1 m resolution is shown. The bright blue areas indicate weak backscatter and are regions of the thickest snow drifts. The yellow and red areas have strong backscatter and are associated with the snow shallows.